**<span style="color:red">Fourth DRAFT</span>**


**HAWAII BENTHIC HABITAT CLASSIFICATION SCHEME**

**FOR MAPPING OF MAIN 8 HAWAIIAN ISLANDS:**


**August 15, 2000**


**PREPARED BY**

**NOAA'S NATIONAL OCEAN SERVICE**
**NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE**
**CENTER FOR COASTAL MONITORING AND ASSESSMENT**
**BIOGEOGRPAHY & REMOTE SENSING PROGRAMS**


**IN COOPERATION WITH FEDERAL, STATE, ACADEMIC, & PRIVATE**
**SECTOR PARTNERS FOR THE DEVELOPMENT OF HAWAII DIGITAL**
**BENTHIC HABITATS MAPS IN RESPONSE TO THE**
**US CORAL REEF TASK FORCE NATIONAL ACTION PLAN**

## Background:

NOAA's National Ocean Service (NOS) is attempting to acquire comprehensive aerial photographs for the nearshore waters of the main 8 Hawaiian Islands. In addition, a hyperspectral experiment will be conducted in Kanehoe Bay on O'hau and complement efforts to obtain hyperspectal imagery for portions of the main 8 islands. The imagery will encompass the area from the shoreline out to about 20 meters in water depth. The images will be used to create digital maps of Hawaii's marine benthic habitats including coral reefs, algal flats, seagrass beds, mangrove forests, and other important habitats for fisheries, tourism, and other aspects of the coastal economy. An initial step in producing benthic habitat maps is the development of a habitat classification scheme. The purpose of this document is to continue the process to develop the benthic habitat classification scheme for the aerial photography and hyperspectral imagery for the main 8 Hawaiian islands. **Complementary schemes will be required for the Northwest Island Hawaiian Islands and other US areas in the Pacific (e.g. Guam).**

The applied mapping component of this project is the use of digital aerial photography as the source data to develop benthic habitat maps from visual interpretation using "heads up" (on screen) computer digitizing. If all of the 92 flight lines are eventually flown (63 lines have be flown in 2000), about 1,700 photographs will need to be scanned, georeferenced, mosaiced, and interpreted based upon expert visual interpretation. In some instances, automated multispectral image analysis (e.g. R-G-B classification) may be used to obtain a crude level of classified map product (e.g. hardbottom, sand, and algae). Regardless of the technique used to interpret the photographs, it is a very time consuming to develop digital photographs into georectified mosaics that are suitable for visual interpretation. Thus, a very important complementary component of the mapping of the Hawaiian Islands is the collection of imagery using a hyperspectral scanner. The hyperspectral imagery is digital and can be georeferenced "on the fly". The first objective of the hyperspectral experiment is to show that for a large region a hyperspectral scanner can be used to produce digital georeferenced imagery that has equal, or greater feature detection quality, when compared to aerial photography. The hyperspectral imagery must be of sufficient quality to enable visual interpretation of the imagery into classified habitat maps. A second objective of the hyperspectral component, is to demonstrate that computer algorithms can automatically classify the digital imagery based upon the spectral characteristics of specific habitats (e.g. coral, sand, algae).

Regardless of whether aerial photographs or hyperspectal imagery are used to map the Hawaiian Islands, either set of imagery will need to be classified into levels of classification that meet the needs of both the management and scientific community. The fourth draft of the classification scheme is an important step in determining the type of map products to be produced from the aerial imagery. To facilitate development of the digital benthic habitat maps, NOAA and its partners will produce a Classification Manual that will document the specific methods used in image interpretation and habitat classification. Components of the Classification Manual will include: list of the classified habitats, description of the habitats, and a decision system for assigning habitat classifications using either aerial photography or hyperspectral imagery. In addition, portions of the hierarchical classification scheme can be used to classify satellite imagery. This is an important aspect of the scheme as it will enable a "common language" compare and contrast digital maps developed from complementary remote sensing platforms.

## Developing the Classification Scheme:

A hierarchical classification scheme will be used to define and delineate habitats. The draft classification scheme was influenced by many factors including: requests of the management community, NOS's coral reef mapping experiences, existing classification schemes for the Pacific and Hawaiian Islands and other coral reef ecosystems, quantitative habitat data for the Hawaiian Islands, the minimum mapping unit (MMU, 1 acre for visual photointerpretation, to be determined for hyperspectal image interpretation), and anticipated limitations of the data. **Most important, if a feature (e.g., habitat) cannot be detected or**

**seen in the photographs or hyperspectral imagery or classified by its spectral signature, it is not included in the scheme.**

The classification scheme is hierarchical to allow users to expand or collapse the detail of the resulting map to suit their needs, but also to allow image interpreters to classify benthic communities to the most accurate resolution possible from each mapping technique (see "Decision System for Assigning Zones and Habitats" and "List of Zones and Habitats" for resolving ability of each technique). For example, hyperspectral supervised classification can distinguish coral reef/hardbottom from some other benthic features (e.g. submerged vegetation, sediment, etc.) but, unlike visual photointerpretation, cannot discriminate between discrete types of coral formations such as patch or spur and groove reefs. Furthermore, users will be encouraged to add information into the GIS if they have more detailed knowledge or data for specific areas. For example, habitat polygons delineated as patch reef using this scheme could be further attributed with species specific information (e.g., Porities sp).

Habitat definitions take both a descriptive as well as empirical approach. Descriptive text will be part of "Description of Zones and Habitats" section and analytical information included in "Decision System for Assigning Zones and Habitats" section. The "Decision System for Assigning Zones and Habitats" section will provide detailed methodologies for map production by either the use of aerial photography or hyperspectral imagery. You will note that the current document has only place-holders for these sections. Decision systems will be based on quantitative and qualitative information (e.g. percent cover, texture, or spectral signatures) in the scanned photograph and hyperspectral data, as well as information from field surveys in the Hawaiian Islands. The "Description of Zones and Habitats" section will provide readable descriptions of habitats for managers and other users less interested in the Decision System methodology.

General Description of the Classification Scheme:

The classification scheme defines benthic communities based on two attributes: large geographic "zones" which are composed of smaller "habitats." Zone refers only to benthic community location and habitat refers only to substrate and cover type (i.e. structure). Every polygon or group of pixels on the benthic community map will be assigned a habitat within a zone (e.g. sand in the lagoon, or sand on the back reef). Zone indicates polygon location and habitat indicates composition of each benthic community delineated. Combinations of habitat and zone that are analogous to traditionally used terminology are noted in the Description section where appropriate. The zone/habitat approach to the classification scheme was developed by combining fisheries models (concept design by Caribbean Fishery Management Council; K. Lindeman, Environmental Defense; and NOS/Biogeography Team - http://biogeo.nos.noaa.gov/benthicmap/caribbean; http://biogeo.nos.noaa.gov/carib-efh/). In addition the draft Hawaii scheme was formulated by integrating information from Gulko (1998), Holthus and Maragos (1995) Pacific Island classification scheme, Allee et al. (unpublished classification scheme), NOAA (2000), benthic habitat maps previously developed for O'hau (State of Hawaii 1981), Puerto Rico (Kruer, 1995; Reid and Kruer, 1998; Lindeman *et al,*1998), and other coral reef systems (Shepard et al., 1995; Chauvaud et al., 1998; Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute and NOAA, 1998; Mumby *et al,*1998), *in situ* Hawaii benthic habitat data, and preliminary analysis of Hawaiian Island aerial photographs.

Eight mutually exclusive zones were identified between land and open water corresponding to insular shelf and coral reef geomorphology. These zones include: island vertical walls, shoreline/intertidal, lagoon, backreef, reef crest, forereef, bank/shelf, and bank/shelf escarpment. Zone refers only to each benthic community's location and does not address substrate or habitat types found within a zone. For example, the lagoon zone may include patch reefs, sand, and seagrass beds, however, these are considered structural elements that may or may not occur within the lagoon zone and therefore, are not used to define the zone.

Thirty-six distinct habitats (e.g. sand, coralline algae, patch reef) were identified that could be mapped by aerial photography and possibly hyperspectral imagery in conjunction with human interpretation of the imagery. Habitats or features that cover areas smaller than the one acre MMU for

aerial photographs were not considered (e.g. the sand halo surrounding a patch reef is too small to be mapped independently). However, pixel and sub-pixel classifications may be possible using hyperspectral imagery. The finer resolution spatial analyses are a component of the Kanehoe Bay hyperspectral experiments (see http://biogeo.nos.noaa.gov/benthicmap/pacific/ for detailed discussion on Kanehoe Bay hyperspectral experiments). Habitat refers only to each benthic community's substrate and/or cover type and does not address location. Habitats are defined in a collapsible hierarchy ranging from five broad classes (Emergent Mangroves, Submerged Vegetation, Unconsolidated Sediment, Coral/Hardbottom, and Other), to more detailed categories (e.g. algae, individual patch reefs, etc.), to patchiness of some specific features (e.g. 10-50% cover of macroalgae).

The description of each zone and habitat will include example images (aerial images for zones, both underwater and aerial images for habitats). Following the description section, a decision system will be provided (***you will note that ONLY place holders are provided at this time) for assigning zones and habitats including detailed methods for benthic community identification using each mapping technique; visual interpretation of both the aerial photographs and the hyperspectral imagery along with the classification using algorithms based on spectral signatures of particular habitats.

**List of Zones and Habitats:**

## ZONES

**Island Vertical Wall**
**Shoreline Intertidal**
**Lagoon**
**Reef Flat** (w/o Lagoon, see fringing reef figure)
**Back Reef** (w/ Lagoon, see barrier reef figure)
**Reef Crest**
**Fore Reef**
**Shelf**
**Shelf Escarpment**
**Unknown**

**Conceptual Cross-section of Zones and Other Features:**

**Barrier Reef System**

Mean High Tide

Spring Low Tide

Shoreline/
Intertidal | Lagoon | Backreef | Reef Crest | Forereef | Shelf | Shelf
Escarpment

**Fringing Reef System**

Mean High Tide

Spring Low Tide

Shoreline/
Intertidal | Reef Flat | Reef Crest | Forereef | Shelf | Shelf
Escarpment
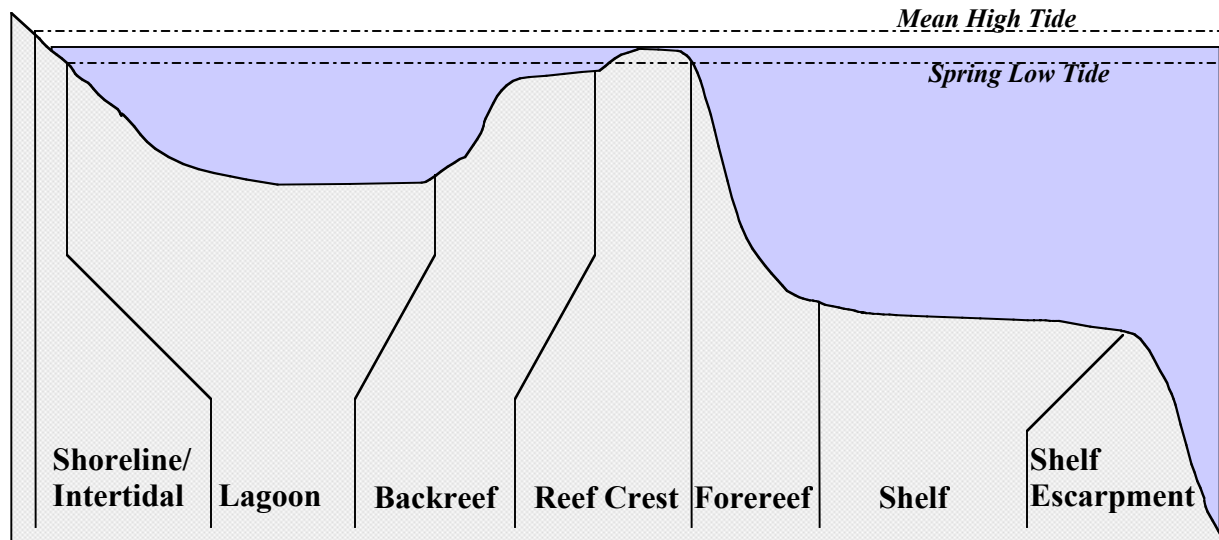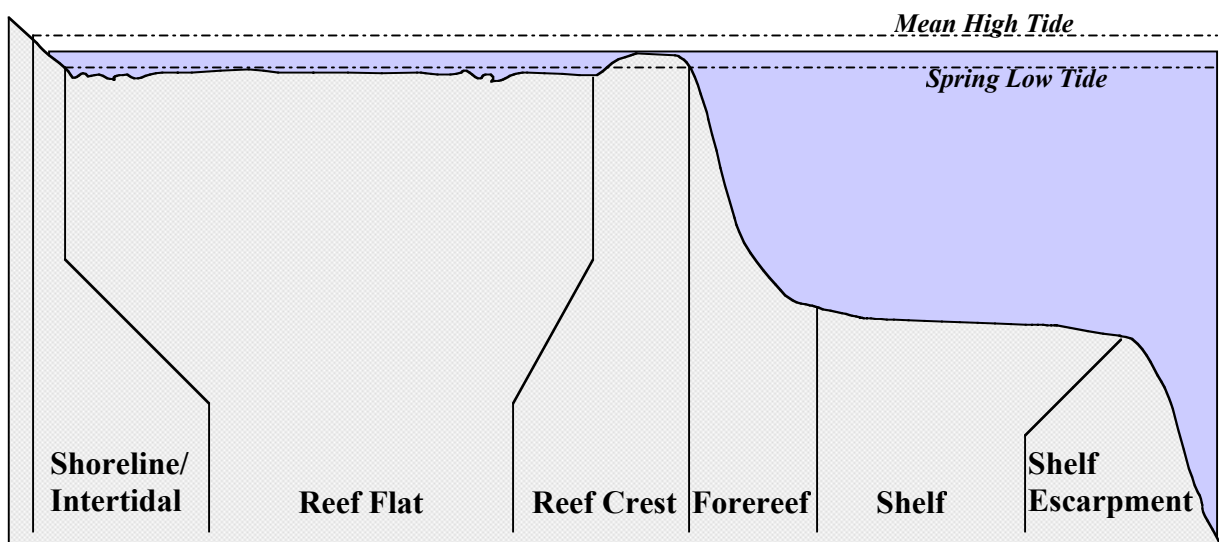
**All, some, or one zone, may be present for any particular area.**

**HABITATS**

**Unconsolidated Sediments (0%-<10% submerged vegetation)**
  **Sand**
  **Mud**

**Submerged Vegetation**
  **Seagrass**
    **Continuous Seagrass (90%-100% Cover)**
    **Patchy (Discontinuous) Seagrass (50%-<90% Cover)**
    **Patchy (Discontinuous) Seagrass (10%-50% Cover)**

  **Macroalgae (fleshy and turf)**
    **Continuous Macroalgae (90%-100% Cover)**
    **Patchy (Discontinuous) Macroalgae (50%-<90% Cover)**
    **Patchy (Discontinuous) Macroalgae (10%-<50% Cover)**

**Coral Reef and Hardbottom**
  **Coral Reef and Colonized Hardbottom**
    **Linear Reef**
    **Spur and Groove**
    **Patch Reef (Individual)**
    **Patch Reef (Aggregated)**
    **Scattered Coral/Rock in Unconsolidated Sediment**
    **Coral Head (Individual)**
    **Coral Head (Aggregated)**
    **Colonized Pavement**
    **Colonized Volcanic Rock/Boulder**
    **Colonized Pavement with Sand/Surge Channels**
    **Colonized Island Vertical Walls**

  **Uncolonized Hardbottom**
    **Reef Rubble**
    **Uncolonized Pavement**
    **Uncolonized Volcanic Rock/Boulder**
    **Uncolonized Pavement with Sand Channels**
    **Uncolonized Island Vertical Wall**

  **Encrusting/Coralline Algae**
    **Continuous Encrusting/Coralline Algae (90%-100% Cover)**
    **Patchy (Discontinuous) Encrusting/Coralline Algae (50%-<90% Cover)**
    **Patchy (Discontinuous) Encrusting/Coralline Algae (10%-50% Cover)**

**Other Delineations**
  **Land**
  **Mangrove**
  **Artificial**
  **Dredged**
  **Cultural**
  **Military**
  **Ship Groundings**
  **Unknown**

**Example Sections (note: Hawaii specific photos will be included when available)**

<u>Descriptions and Examples of Zones and Habitats:</u>

## Geomorphology

**Fringing Reef:** Reef platform continuous with the shore.

**Barrier Reef:** Reef separated from the shore by a relatively wide, deep lagoon.

**Atoll:** Reef surrounding a lagoon. (definition included for comparison)

## Zones

**Island Vertical Wall:** Area with near-vertical decline from shore to shelf or shelf escarpment.  This zone is typically narrow and may not be distinguishable in aerial photography.

> **Typical Habitats:** volcanic rock, algae, coral.

**Shoreline Intertidal:** Area between the mean high water line (or landward edge of mangroves when they are present) and lowest spring tide level (does not include emergent segments of barrier reefs).

> **Typical Habitats:** Mangrove, sand beach, very shallow sand and seagrass, and colonized and uncolonized volcanic/carbonate rock.
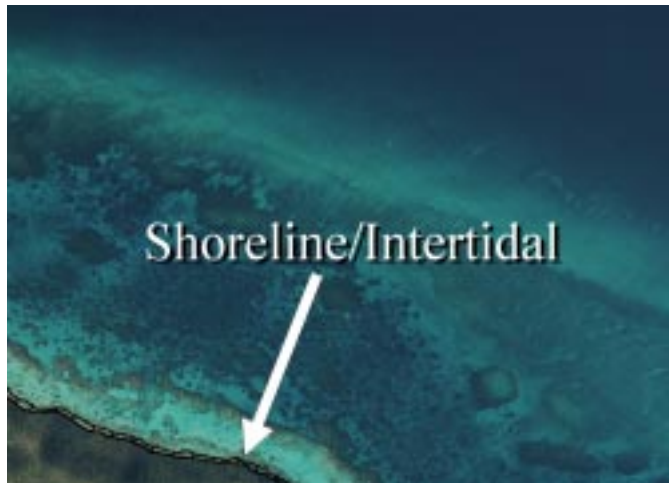


**Lagoon:** Shallow area (relative to the deeper water of the shelf) between the shoreline intertidal zone and the back reef of a reef or a barrier island.  This zone is protected from the high-energy waves commonly experienced on the shelf and reef crest.  If no reef crest is present there is no lagoon zone.

> **Typical Habitats:** Sand, seagrass, algae, pavement, volcanic/carbonate rock, and patch reefs.

**Reef Flat:** Shallow (semi-exposed) area between the shoreline intertidal zone and the reef crest of a fringing reef. This zone is protected from the high-energy waves commonly experienced on the shelf and reef crest. Reef flat is typically not present if there is a lagoon zone.

> **Typical Habitats:** Sand, reef rubble, seagrass, algae, and patch reef.

**Back Reef:** Area between the seaward edge of a lagoon floor and the landward edge of a reef crest. This zone is typically present when a reef crest and lagoon exists.

> **Typical Habitats:** Sand, reef rubble, seagrass, algae, linear reef, and patch reef.



**Reef Crest:** The flattened, emergent (during low tides) or nearly emergent segment of a reef. This zone lies between the back reef and fore reef zones. Breaking waves will often be visible in aerial images at the seaward edge of this zone.

> **Typical Habitats:** Reef rubble, algal ridge, and linear reef.

**Fore Reef:** Area from the seaward edge of the reef crest that slopes into deeper water to the landward edge of the bank/shelf platform.

> **Typical Habitats:** Linear reef and Spur and Groove.



**Shelf:** Deep water area (relative to the shallow water in the lagoon) extending offshore from the seaward edge of the fore reef to the beginning of the escarpment where the insular shelf drops off into deep, oceanic water. The Shelf is the flattened platform between the fore reef and deep open ocean waters or between the shoreline/intertidal zone and open ocean if no reef crest is present.

> **Typical Habitats:** Sand, patch reefs, algae, seagrass, linear reef, colonized and uncolonized pavement, colonized and uncolonized pavement with sand channels, and other coral reef habitats.

**Shelf Escarpment:** The edge of the shelf where depth increases rapidly into deep, oceanic water. This zone begins at approximately 20 to 30 meters deep, near the depth limit of features visible in aerial images. This zone extends well into depths exceeding those that can be seen on aerial photographs and is intended to capture the transition from the shelf to deep waters of the open ocean.

> **Typical Habitats:** Sand, linear reef, and spur and groove.

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**Habitats:** (***aerial and underwater images will be added in subsequent drafts***)

**Unconsolidated Sediments:** Unconsolidated sediment with <10% cover of submerged vegetation.

> **Mud:** Fine sediment often associated with river discharge and buildup of organic material in areas sheltered from high-energy waves and currents.

> **Sand:** Coarse sediment typically found in areas exposed to currents or wave energy.

**Submerged Vegetation:** Greater than 10% cover of submerged vegetation in unspecified substrate type (usually sand, mud, or hardbottom).

> **Seagrass:** Habitat with 10% or more cover of seagrass (e.g., *Halophila sp.*).
> > **Continuous Seagrass:** Seagrass covering 90% or more of the substrate. May include blowouts of less than 10% of the total area that are too small to be mapped independently (<MMU). This includes continuous beds of any shoot density (may be a continuous sparse or dense bed).
> > **Patchy Seagrass:** Discontinuous seagrass with breaks in coverage that are too diffuse or irregular, or result in isolated patches of seagrass that are too small (smaller than the MMU) to be mapped as continuous seagrass.
> > > **Patchy Seagrass (50%-90% cover)**
> > > **Patchy Seagrass (10%-50% cover)**
> >
> > > **Representative Species:**
> > > *Halophila sp.*

> **Macroalgae:** An area with 10% or greater coverage of any combination of numerous species of red, green, or brown macroalgae (e.g., fleshy & turf). Usually occurs in shallow backreef and deeper waters on the bank/shelf zone.
> > **Continuous Macroalgae:** Macroalgae covering 90% or greater of the substrate. May include blowouts of less than 10% of the total area that are too small to be mapped independently (<MMU). This includes continuous beds of any shoot density (may be a continuous sparse or dense bed).
> > **Patchy Macroalgae:** Discontinuous macroalgae with breaks in coverage that are too diffuse or irregular, or result in isolated patches of macroalgae that are too small (smaller than the minimum mapping unit) to be mapped as continuous macroalgae.
> > > **Patchy Macroalgae (50%-<90% cover)**
> > > **Patchy Macroalgae (10%-<50% cover)**
> >
> > > **Representative Species:**
> > > *Dictyosphaeria spp.*
> > > *Halimeda spp.*

**Coral Reef and Hardbottom:** Hardened substrate of unspecified relief formed by the deposition of calcium carbonate by reef building corals and other organisms (relict or ongoing) or existing as exposed bedrock.

> **Coral Reef and Colonized Hardbottom:** Substrates formed by the deposition of calcium carbonate by reef building corals and other organisms. Habitats within this category have some colonization by live coral, unlike the **Uncolonized Hardbottom** category.

> **Linear Reef:** Linear coral formations that are oriented parallel to shore or the shelf edge. These features follow the contours of the shore/shelf edge. This category is used for such traditional terms as fore reef, fringing reef, and shelf edge reef.

**Spur and Groove:** Habitat having alternating sand and coral formations that are oriented perpendicular to the shore or bank/shelf escarpment. The coral formations (spurs) of this feature typically have a high vertical relief (relative to pavement with sand channels, see below) and are separated from each other by 1-5m of sand or bare hardbottom (grooves), although the height and width of these elements may vary considerably. This habitat type typically occurs in the fore reef or bank/shelf escarpment zone.

**Patch Reef(s):** Coral formations that are isolated from other coral reef formations by sand, seagrass, or other habitats and that have no organized structural axis relative to the contours of the shore or shelf edge.

> **Individual patch reef**: Distinctive *single* patch reefs that are larger than or equal to the MMU.
> **Aggregate patch reefs:** *Clustered* patch reefs that individually are too small (smaller than the MMU) or are too close together to map separately.
> **Scattered Coral/Rock in Unconsolidated Sediment:** Primarily sand or seagrass bottom with scattered rocks or small, isolated coral heads that are too small to be delineated individually (i.e. smaller than "individual patch reef").

**Coral Head(s)**: Large coral heads that are isolated from other coral reef formations by sand, seagrass, or other habitats and that have no organized structural axis relative to the contours of the shore or shelf edge. This category may be mapped even if smaller than the MMU.

> **Individual coral head**: Distinctive *single* coral heads that are larger than or equal to the MMU.
> **Aggregate coral heads**: Clustered coral heads that individually are too small (smaller than the MMU) or are too close together to map separately.

**Colonized Pavement:** Flat, low-relief, solid volcanic/carbonate rock with coverage of macroalgae, hard coral, zoanthids, and other sessile invertebrates that are dense enough to begin to obscure the underlying carbonate rock.

**Colonized Volcanic Rock:** Exposed (nearshore) volcanic rock that has coverage of macroalgae, hard coral, zoanthids, and other sessile invertebrates that begins to obscure the underlying rock.

**Colonized Pavement with Sand/Surge Channels:** Habitat having alternating sand and colonized pavement (see above) formations that are oriented perpendicular to the shore or bank/shelf escarpment. The sand/surge channels of this feature have low vertical relief (relative to Spur and Groove formations). This habitat type occurs in areas exposed to moderate wave surge such as the bank/shelf zone.

**Representative Species/Live Coral Community:**
*Porites compressa*
*Porites lobata*
*Montipora* spp.
*Pocillopora meandrina*

**Colonized Vertical Island Walls:** Unique habitat that some low-light coral and bryozoans colonize along the vertical  walls of island shorelines.

**Uncolonized Hardbottom:** Hard substrate composed of relict deposits of calcium carbonate or exposed volcanic rock.

**Reef Rubble:** Dead, unstable coral rubble often colonized (but not always) with filamentous or other macroalgae. This habitat often occurs landward of well developed reef formations in the reef crest or back reef zone.

**Uncolonized Pavement:** Flat, low relief, solid volcanic/carbonate rock that is often covered by a thin sand veneer. The pavement's surface often has *sparse* coverage of macroalgae, hard coral, zoanthids, and other sessile invertebrates that does not obscure the underlying volcanic/carbonate rock.

**Uncolonized Volcanic Rock/Boulder:** Exposed volcanic rock that has s*parse* coverage of macroalgae, hard coral, zoanthids and other sessile invertebrates that does not obscure the underlying rock.

**Uncolonized Pavement with Sand Channels:** Habitat having alternating sand and uncolonized pavement (see above) formations that are oriented perpendicular to the shore or bank/shelf escarpment. The sand channels of this feature have low vertical relief (relative to Spur and Groove formations). This habitat type occurs in areas exposed to moderate wave surge such as the shelf zone.

**Uncolonized Vertical Island Walls:** Unique habitat along the vertical walls of island shoreline.

**Encrusting/Coralline Algae:** An area with 10% or greater coverage of any combination of numerous species of red (dominant), green, or brown macroalgae. May occur in shallow backreef, relatively shallow waters on the shelf zone, and at depth.

    **Continuous Encrusting/Coralline Algae:** encrusting/coralline algae covering 90% or more of the substrate.

    **Patchy Encrusting/Coralline Algae:** Discontinuous encrusting/coralline algae with breaks in coverage that are too diffuse or irregular, or result in isolated patches of coralline algae that are too small (smaller than a MMU) to be mapped as continuous coralline algae.

        **Patchy Encrusting/Coralline Algae (50%-<90% cover)**
        **Patchy Encrusting/Coralline Algae (10%-<50% cover)**

    **Representative Species:**
    *Porolithon gardineri*

**Other Delineations:**

**Mangrove:** Emergent habitat composed of primarily of *Rhizophora mangle* (red mangrove). Mangroves are generally found in areas sheltered from high-energy waves. This habitat type is usually found in the shoreline/intertidal or barrier reef crest zone.

**Artificial:** Armored shoreline such as seawalls, submerged or emergent wrecks, dredge spoil, and other man-made habitats.

**Dredged:** Excavated or dredged areas typically with sand or mud bottom.

**Cultural:** Include anchialine ponds and active and remnant fish ponds. Anchialine ponds are natural formations distinctly inland of the shore. Water levels rise and fall with the tide through porous lava. Remnant and active fish ponds are walled off from the open ocean along the shoreline, often along a reef crest.

**Military:** Areas used for military operations which are normally restricted to other activities.

**Ship Groundings: ???**

**Unknown:** Bottom type unknown due to turbidity, cloud cover, or other interference.

## Decision System for Assigning Zones and Habitats

***Note that this is only a place holder for this section.  Detailed information will be included in this section in subsequent drafts***

1.  Visual Interpretation of scanned photographs.
Description of the method and hierarchical classification level expected to be reached with this method.
Error tolerance analysis and method.

2.  Visual Interpretation of digital hyperspectral imagery.
Description of the method and hierarchical classification level expected to be reached with this method.
Error tolerance analysis and method.

3.  Supervised hyperspectral Classification: Image analysis software applied to hyperspectral imagery
Description of the method and hierarchical classification level expected to be reached with this method.
Both pixel and sub-pixel analysis will be undertaken.
Error tolerance analysis and method.

## REFERENCES:

Allee, R.J., and 11 co-authors. 2000 Draft.  Marine and Estuarine Ecosystem Classification. National Marine Fisheries Service.  Office of Habitat Conservation. Silver Spring, MD. 41 p.

Beets, J., L. Leewand, and E.S. Zullo. 1986. Marine community descriptions and maps of bays within the Virgin Islands National Park/Biosphere Reserve.  Biosphere Reserve Research Report No. 2, MAB, NPS, DOI. 118 pp.

Boulon, R.H. 1986. Distribution of fisheries habitats within the Virgin Islands Biosphere Reserve. Biosphere Reserve Research Report No. 8, MAB, NPS, DOI.  56 pp.

Chauvaud, S., C.Bouchon, and R. Maniere. 1998. Remote sensing techniques adapted to high resolution mapping of tropical coastal marine ecosystems (coral reefs, seagrass beds, and mangrove). Int.J.Remote.Sens. 19(18):3525-3639.

Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute and National Oceanic and Atmospheric Administration. 1998. Benthic Habitats of the Florida Keys.  FMRI Technical Report No. TR-4.  52 pp.

Gulko, D. 1998. Hawaiian Coral Reef Ecology. Mutual Publishing. Honolulu, HI. 245 p.

Holthus, P.F., and Maragos, J.E., 1995.  Marine ecosystem classification for the tropical island Pacific. In: Maragos, J.E., Peterson, M.N.A., Eldredge, L.G., Bardach, J.E., Takeuchi, H.F. Eds.), Marine and Coastal Biodiversity in the Tropical Island Pacific Region, East-West Center, Honolulu, pp 239-278.

Kruer, C. 1995. Mapping and characterizing seagrass areas important to manatees in Puerto Rico- Benthic Communities Mapping and Assessment.  Report Prepared for U.S. DoI, Nat. Biol. Serv., Sirenia Project, Order No. 83023-5-0161. 14 pp.

Lindeman, K.C., G.A. Diaz, J.E. Serafy, and J.S. Ault. 1998. A spatial framework for assessing cross-shelf habitat use among newly settled grunts and snappers. Proc. Gulf Carib. Fish. Inst. 50:385-416.

Mumby, P.J., A.R.Harborne, and P.S. Raines.  1998. Draft Classification Scheme for Marine Habitats of Belize.  UNDP/GEF Belize Coastal Zone Management Project.  44 pp.

NOAA. 2000. Benthic habitats of Puerto Rico and the U.S. Virgin Islands: Habitat classification scheme. National Ocean Service, Center for Coastal Monitoring and Assessment, Biogeography Program, Silver Spring, MD. 14pp.

Reid, J.P., and C.R. Kruer. 1998. Mapping and characterization of nearshore benthic habitats around Vieques Island, Puerto Rico. Report to U.S. Navy. U.S. Geological Survey/BRD, Sirenia Project, Gainesville Florida. 11pp.

Sheppard, C.R., K. Matheson, J.C. Bythel, P.Murphy, C.B.Myers, and B.Blake. 1998. Habitat mapping in the Caribbean for management and conservation: Use and Assessment of Aerial Photography. Aquat.Cons. 5:277-298

State of Hawaii 1981. O'hau Costal Zone Atlas: Hawaii Coral Reef Inventory Island of O'hau. Part C.1. Harbors Division Dept. of Transportation. Honolulu, HI.

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